The Indirect Effects of Aerosols on Climate

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Understanding the changes in our climate has been a major issue for the past decade. Issues dealing with the effects of global warming, which results from greenhouse gases has lead the way to vast research. Now, researchers have realized that it's not only the greenhouse gases, which affect our climate but aerosols as well. The point of this paper is to understand and demonstrate the need for continued research in the field of atmospheric aerosols and their indirect effect on the climate.

Some clarification needs to be made on the differences between direct and indirect effects of aerosols on climate. First of all, atmospheric aerosols affect the Earth's radiative balance directly by scattering or absorbing of light (i.e. direct effect). Indirect effects of atmospheric aerosols implies that the aerosols serve as cloud condensation nuclei (CCN), thereby influencing the albedo and lifetime of clouds. This paper deals with the latter of the two effects.

How do aerosols affect the climate indirectly? Many studies have demonstrated various answers to this question. There has been a substantial increase in anthropogenic emissions over the past century, as demonstrated in figure 1.

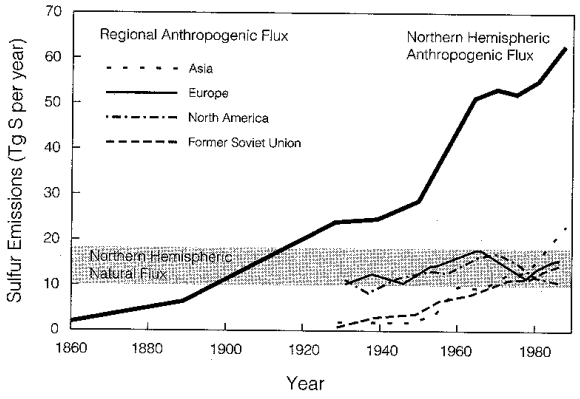

FIGURE 1.1 Estimated Northern Hemisphere and regional anthropogenic sulfur emissions over the past century. SOURCE: Dignon and Hameed (1989); Dignon and Gene (1995).

Fig. 1

This increase in anthropogenic emissions (i.e. higher concentration of aerosols put into the atmosphere) affects the atmosphere indirectly leading to changes in climate. By increasing the concentration of aerosols into the atmosphere, the number concentration of cloud droplets may increase. This increase in cloud droplet concentration enhances scattering of light within the clouds and leads to an increase in the optical depth of the cloud. It has also been noted that the areal extent of the cloud may also increase (e.g. larger droplet numbers yielding smaller droplets, slower coalescence, and thus longer droplet lifetimes, or organic material slowing the rate of evaporation of droplets)[1]. This is the essence of the indirect effects of clouds on climate.[2] So, the obvious key is to measure the number concentration of cloud condensation nuclei to get a picture of the influences on the number concentration of cloud droplets. Cloud condensation nuclei are particles that will activate to form cloud droplets at a given supersaturation of water. Other meteorological influences such as precipitation might occur as a result of perturbations in the number and concentrations of aerosols; however such effects have yet to be assessed qualitatively.[3]

Taking a look at maritime air masses vs. continental air masses. It has been well documented through various studies that the CCN concentrations are much greater in continental air masses than in maritime air masses. The understanding here is rather simple. Maritime air masses are rarely under the influence of anthropogenic emissions and rarely exceed 100 cm^{-3}, whereas in well aged continental air masses, the value

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[1] Panel on Aerosol Radiative Forcing and Climate Change, Board of Atmospheric Sciences and Climate, Commission on Geosciences, Environment, and Resources, National Research Council, A Plan For a Research Program: Aerosol Radiative Forcing and Climate Change, National Academy Press, 1996, p. 12.
[2] Seinfeld, John H. and Pandis, Spyros N., Atmospheric, chemistry, and physics: From Air Pollution to Climate Change, John Wiley & Sons, 1998, p. 1170

generally exceeds 1000 cm^{-3}.[4] Several studies have been done which support the statement that anthropogenic emissions are greater in continental air masses than that of maritime air masses. Twomey et al, 1978, conducted measurements of CCN and concluded that after relatively clean air (CCN as low as 50 cm^{-3}) increased to 4500 cm^{-3} after this air passed over an industrial area in southeast Australia. Radke and Hobbs, 1976, measured CCN concentration values of 1000 to 3500 cm^{-3} in air advecting off the eastern seaboard of the United States. Hudson, 1991, conducted CCN measurements along the west coast of the United States and revealed measurements of 20 to 40 cm^{-3} for marine air, 100 to 200 cm^{-3} in non-urban inland areas in Oregon, and 3000 to 5000 cm^{-3} in urban areas in the vicinity of Santa Cruz, CA.[5] Clearly, continental clouds have greater cloud droplet number concentrations than do marine clouds. High cloud droplet number concentrations have been linked closely to industrial sources (figure 2).

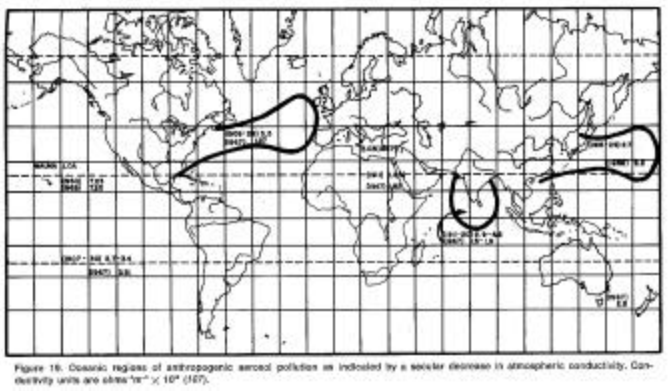

Fig. 2

[3] Panel on Aerosol Radiative Forcing and Climate Change, Board of Atmospheric Sciences and Climate, Commission on Geosciences, Environment, and Resources, National Research Council, A Plan For a Research Program: Aerosol Radiative Forcing and Climate Change, National Academy Press, 1996, p. 12.
[4] Seinfeld, John H. and Pandis, Spyros N., Atmospheric, chemistry, and physics: From Air Pollution to Climate Change, John Wiley & Sons, 1998, p. 1170
[5] Seinfeld, John H. and Pandis, Spyros N., Atmospheric, chemistry, and physics: From Air Pollution to Climate Change, John Wiley & Sons, 1998, p. 1170

Numerous studies have demonstrated this. Warner and Twomey, 1967, the number concentration of aerosols in clouds downwind of sugarcane fires averaged 510 cm^{-3} as compared to upwind measurements of 104 cm^{-3}. Fitzgerald and Spyers Duran, 1973, observed the same downwind effects in St. Louis, MO as Warner and Twomey did in 1967. Alkezweeny et al., 1993, studied upwind and downwind cloud droplet size distribution for Denver, CO. Droplet size distribution of downwind air shifted to smaller droplet diameters than that of the upwind airs (14 micrometers versus 28 micrometers). The volume median droplet concentration increased from 22 cm^{-3} to 226 cm^{-3}. Hudson and Li, 1995, found significantly larger droplet concentrations and smaller mean drop diameters in polluted clouds as compared to non-polluted clouds. Drizzle also appeared to be suppressed in the polluted clouds. Saxena et al., 1996 measured cloud droplet number concentrations and ionic composition of cloud water at Mount St. Mitchell, North Carolina. In general, more acidic clouds were found to have smaller effective radii of droplets but larger cloud droplet number concentrations, indicated that the sulfur content of air masses is capable of changing the microphysical characteristics of clouds.[6]

Ship tracks have also been studied thoroughly because aerosols emitted or formed from the exhaust of ships form linear features of high cloud reflectivity embedded into marine stratus clouds.[7] Figure 3 illustrates this feature.

[6] Seinfeld, John H. and Pandis, Spyros N., Atmospheric, chemistry, and physics: From Air Pollution to Climate Change, John Wiley & Sons, 1998, p. 1170

[7] Seinfeld, John H. and Pandis, Spyros N., Atmospheric, chemistry, and physics: From Air Pollution to Climate Change, John Wiley & Sons, 1998, p. 1170

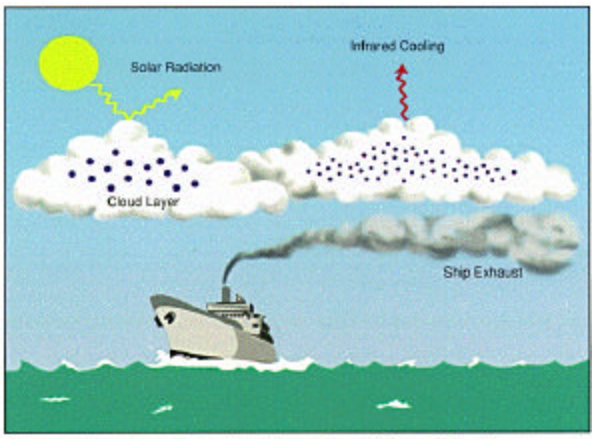

Figure 2: Illustration depicting the effects of aerosols from ship exhaust on cloud reflectivity

Fig. 3

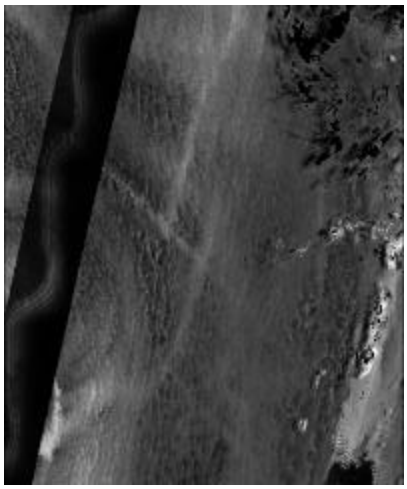

Fig. 4

Figure 4 is just a classic illustration of what ship tracks look like utilizing satellite imagery. Numerous studies have been conducted on how ship tracks form. Radke et al., 1989, King et al., 1993, and Johnson et al., 1996, concluded from aircraft observations, aerosols emitted or formed from the ships exhaust increased droplet concentrations and decreased drop sizes in the ship tracks themselves as compared with the adjacent, unperturbed regions of the clouds.[8] Figure 5 is a great illustration of ship tracks and showing the relation to cloud droplet number concentrations and particle diameter.

[8] Seinfeld, John H. and Pandis, Spyros N., Atmospheric, chemistry, and physics: From Air Pollution to Climate Change, John Wiley & Sons, 1998, p. 1170

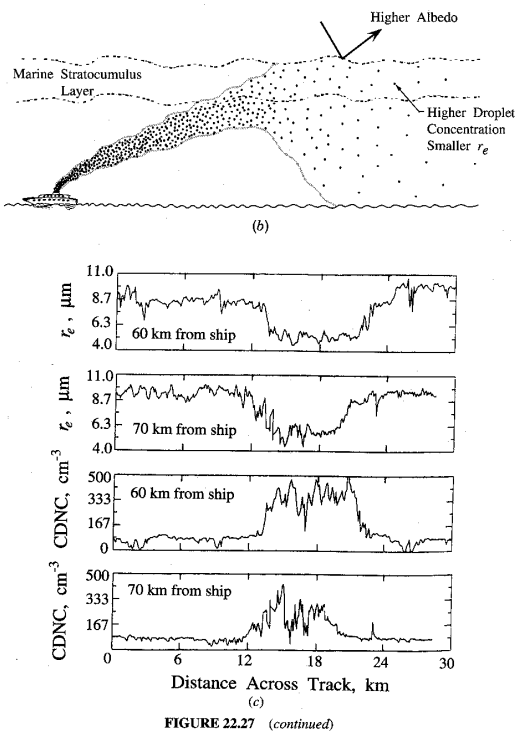

FIGURE 22.27 (*continued*)

Fig. 5

Probably, one of the most important aerosols to track, is the emission of sulfate aerosols into the atmosphere. The indirect effects of aerosols on climate are, illustrated by processes that link SO_2 emissions to an increase in albedo. Sulfur dioxide is oxidized in the gas and aqueous phases to aerosol sulfate.[9] Although increases in sulfur dioxide emissions can be expected to lead to an increase in the mass of sulfate aerosol, the relationship between an increased mass of aerosol and corresponding changes in the number concentrations of aerosols is not well established.[10] The aerosol number concentration is closely linked to the cloud drop number concentration. The mass of

[9] Seinfeld, John H. and Pandis, Spyros N., Atmospheric, chemistry, and physics: From Air Pollution to Climate Change, John Wiley & Sons, 1998, p. 1171-72

[10] Seinfeld, John H. and Pandis, Spyros N., Atmospheric, chemistry, and physics: From Air Pollution to Climate Change, John Wiley & Sons, 1998, p. 1171-72

aerosol is created by the gas-to particle conversion and occurs by growth of existing particles or the nucleation of fresh particles. The route that predominates determines the aerosol number concentration. From growth of existing particles leads to fewer larger particles, while nucleation of fresh particles leads to many smaller particles. Obviously, the particle lifetime is dependent on the size of the particle. The smaller particles have much shorter lifetimes due to the coagulation and scavenging processes, which occur in clouds.[11] Precipitation in clouds is formed by and dependent on the cloud drop size distribution. Precipitation is accelerated, for a given liquid water content, with fewer larger drops than with a greater number of smaller drops. One possible effect of reduced cloud droplet size is an increase in the cloud lifetime resulting from a decrease tendency for precipitation.[12] The chain of events described above from anthropogenic emission of sulfate leads to cloud albedo changes. Figure 6 illustrates the volcanic and industrial emission of sulfate into the atmosphere and it's effect directly and indirectly on climate.

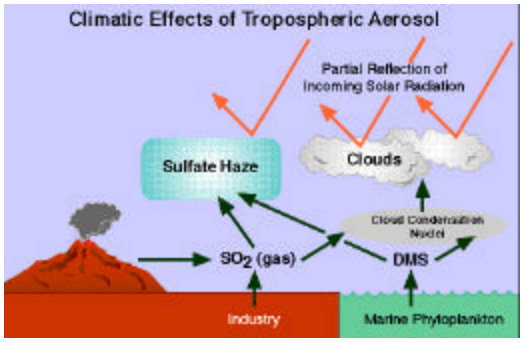

Fig. 6

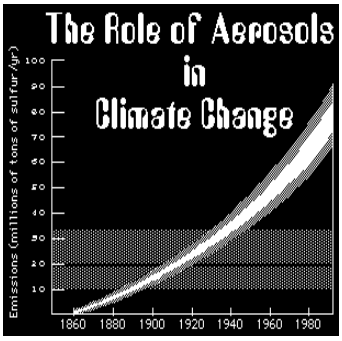

Fig. 7

[11] Seinfeld, John H. and Pandis, Spyros N., Atmospheric, chemistry, and physics: From Air Pollution to Climate Change, John Wiley & Sons, 1998, p. 1171-72

[12] Seinfeld, John H. and Pandis, Spyros N., Atmospheric, chemistry, and physics: From Air Pollution to Climate Change, John Wiley & Sons, 1998, p. 1172

Figure 7 is an illustration of how the amount of sulfur in the atmosphere has increased in the atmosphere over the last century.

Now that we have covered past studies and the results of those studies which loosely explain the indirect effects of aerosols on climate. What is being done in the present to get to the bottom of how aerosols effect the climate? Many projects are being funded to research this area. Here are a few:

1. **ACE-Asia** (Asian Pacific Regional Aerosol Characterization Experiment): The effects of clouds on aerosol properties and the effects of aerosols on cloud properties (indirect aerosol effect) will be quantified in focused intensive experiments.

2. **INDOEX** (Indian Ocean Experiment): The goal of this project is to document the chemical and physical properties of natural and human produced atmospheric aerosols and use these observations to study and model the complex interactions among atmospheric aerosols, clouds, and climate.

3. **ACE-I** (Aerosol Characterization Experiment I): The goal is provide data on: the chemical composition, size distribution, and radiative and cloud nucleating properties of aerosols in the marine atmosphere, the amount of biogenic sulfur (DMS) released from the ocean to the atmosphere, the rates and efficiencies of sulfur gas oxidation in the marine atmosphere, and the rates and efficiencies of the processes controlling the formation, growth, distribution, and removal of particles in the marine atmosphere.

In conclusion, the indirect effects of aerosols on climate are just as important if not more important than the direct effects in contributing to radiative forcing. The aerosols that are put into the atmosphere by humans and some naturally needs to be monitored closely. How drastically this effect will mean on our climate is still unanswered. Research programs, especially ACE, need to continue to help answer this question. Modeling of this problem is especially tough but through our persistence, we can control emissions and make models, which will change our thinking into making this planet a safe living environment for many years to come.

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